



INSTITUTE FOR DEFENSE ANALYSES

**Applying the Integrated Risk
Assessment and Management Model
(IRAMM) to the Assessment of Risk for
Non-fuel Strategic Materials**

Kevin E. Burns

James S. Thomason, Project Leader

J. Darrell Morgeson

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Executive Summary

The Integrated Risk Assessment and Management Model (IRAMM) is used as part of a decision-support process that the Department of Defense (DOD) and, more broadly, the United States Government (USG) now employ to assess risks and identify cost-effective risk mitigation strategies in the area of non-fuel strategic materials. The strategic material decision-support process (the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)) is used to assess risks and set priorities for preparedness programs designed to mitigate potential strategic material shortfalls. IRAMM provides the strategic risk context for RAMF-SM risk assessments.

IRAMM is a flexible approach to strategic risk assessment that employs structured, interactive one-on-one interviews with national security experts. The interviews are structured around four categories known as Challenge Areas that are defined so that together they cover a full range of potential operations conducted by the U.S. military during the next decade. The results from IRAMM were used as inputs to the RAMF-SM process that helped produce the *Strategic and Critical Materials 2013 Report on Stockpile Requirements* to Congress. IRAMM interviews provided assessments of the probabilities of potential scenarios that pose strategic risk to the Nation. These scenarios included but were not limited to the scenarios specified by Congress for the *2013 Report on Stockpile Requirements*. IRAMM respondents also provided consequences for the strategic risk scenarios as well as important context on how these scenarios might develop in the future. These insights provided the future strategic context for the experts who estimated strategic materials shortfall risks.

Several recent IRAMM enhancements will be applied in the next cycle of RAMF-SM assessments for the *2015 Report on Stockpile Requirements* to Congress. These enhancements include a more rigorous accounting of the future risk-causing scenario space; a generalized approach to estimating risk for a subset of the Challenge Areas; and a revised set of Challenge Areas.

The IRAMM approach to assessing risk is a rigorous way of obtaining DOD senior leadership views on strategic national security strategy, capabilities, and risk. The results can be used in a multitude of ways including informing debate on complex issues, identifying alternative resource strategies, allocating resources, developing rationale for decisions, etc. Previous applications and the flexibility of IRAMM suggest more areas of application than the current use in RAMF-SM. IRAMM would prove useful in any situation where decisions are needed to mitigate risk across disparate areas of concern. There are other potential uses for

IRAMM outside the arena of decision making. For example, it could provide the basis for training exercises at senior military schools.

Contents

1.	Introduction	1
A.	Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM).....	1
B.	Integrated Risk Assessment and Management Model (IRAMM).....	3
C.	Definition of Risk.....	4
2.	2012 Risk Assessment Exercise	7
A.	Background	7
1.	Selection of Experts.....	7
2.	Description of Challenge Areas	8
3.	Consequence Categories.....	9
B.	Description of Elicitation Protocol.....	11
1.	Consequence Calibration.....	11
2.	Order of the Elicitation.....	14
C.	Results	15
1.	Risk Profiles	15
2.	Drivers of Risk	16
3.	Estimating Probabilities for the <i>2013 Report on Stockpile Requirements to Congress</i>	17
3.	Enhancements to the IRAMM Protocol	19
A.	More Complete Scenario Space for Major Combat Operations (MCO).....	19
B.	A Different Approach for the Irregular Warfare (IW) and Homeland Defense (HLD) Challenge Areas	22
C.	Changes to Challenge Areas.....	24
4.	Origin, Value, and Other Applications of IRAMM	25
Appendix A	Illustrations.....	A-1
Appendix B	References	B-1
Appendix C	Abbreviations	C-1

1. Introduction

This paper describes how the Integrated Risk Assessment and Management Model (IRAMM) is used in a decision-support process that the Department of Defense (DOD) and, more broadly, the United States Government (USG) now employ to assess risks and identify cost-effective risk mitigation strategies in the important area of non-fuel strategic materials. Many of these materials, such as beryllium, high-performance fibers, rhenium and rare earths, are essential to daily life in the United States and many defense and critical civilian infrastructure systems. A number of these materials may be in short supply during national emergencies. This paper begins with an overview of the strategic material decision-support process (the Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)) used to assess risks and set priorities for preparedness programs designed to mitigate potential strategic material shortfalls. Next, the paper describes the structure of IRAMM followed by some recent IRAMM results used in the RAMF-SM process that helped produce the *Strategic and Critical Materials 2013 Report on Stockpile Requirements*¹ to Congress. Several recent IRAMM enhancements that will be applied in the next cycle of RAMF-SM assessments—for the *2015 Report on Stockpile Requirements* to Congress—are described next. The paper concludes with observations about the importance of IRAMM within RAMF-SM as well as the potential utility of an IRAMM-like approach to support U.S. national security decisions.

A. Risk Assessment and Mitigation Framework for Strategic Materials (RAMF-SM)

The RAMF-SM process helps identify cost-effective strategies for mitigating potential strategic material disruptions and shortfalls using a risk construct. The major steps of RAMF-SM are shown in Figure 1.

¹ U.S. DOD, *Strategic and Critical Materials 2013 Report on Stockpile Requirements* (Washington, DC: Under Secretary of Defense for Acquisition, Technology and Logistics (USD AT&L), 2013), (hereafter cited as *2013 Report on Stockpile Requirements* or *2015 Report on Stockpile Requirements*, depending on the year of report).

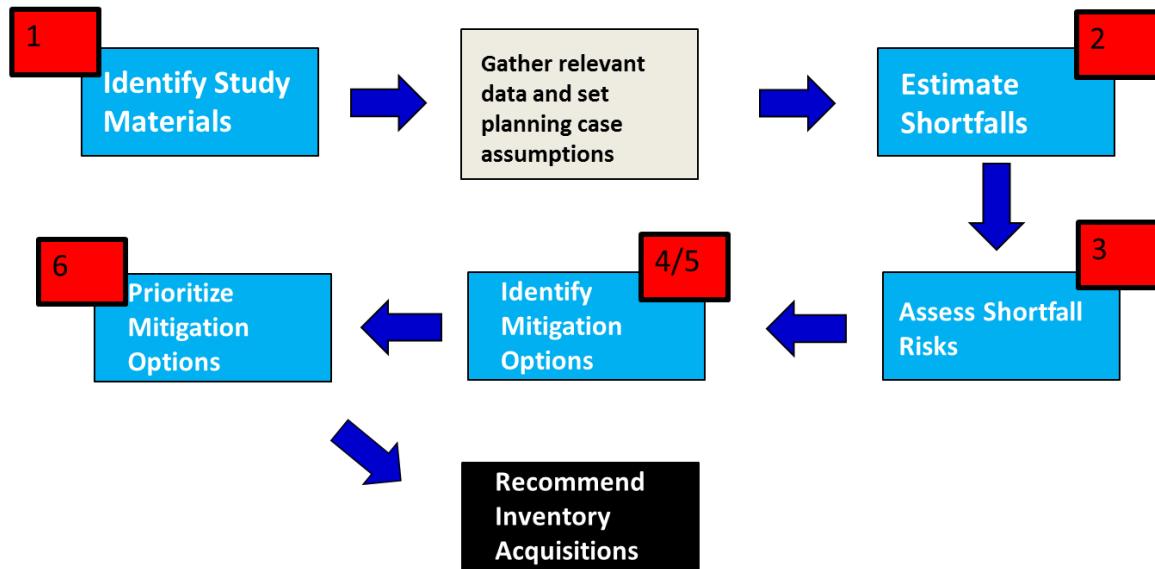


Figure 1. RAMF-SM Process and Steps

RAMF-SM has six major steps. Overall, a suite of interconnected models, hundreds of data bases updated for each new RAMF-SM cycle, and numerous structured assessments by subject matter experts (SME) are involved in its application. The first step in RAMF-SM is to select the set of materials to be assessed in the cycle. The second step is to assess, under mandated postulated scenario conditions, the extent of any shortfalls of supplies of materials for the Nation relative to critical U.S. military and civilian demands for them. The third step of the process flow diagram shown contains two separate steps: the assessment of shortfall risks for unmitigated materials shortfalls, and the IRAMM strategic risk assessment (not shown). The results of the IRAMM strategic risk assessment are used as input into the assessment of risks for unmitigated materials shortfalls. The fourth and fifth steps involve identifying promising options (such as developing special contingency contracts with suppliers, utilizing substitute materials, Federal stockpiling) to mitigate some or all of these shortfalls/risks. These steps include assessing the costs and effectiveness of each mitigation option, and of combinations of them, in terms consistent with the Office of Management and Budget (OMB) guidelines for such estimates. The sixth and final step involves identifying optimal packages of investments in mitigation options—across the whole set of shortfall materials—under various potential budget and time constraints. The primary result of RAMF-SM is a set of recommended mitigation strategies, including investments.

Much of the RAMF-SM structure has now been implemented by the DOD in preparing its recommendations to the Congress to address the risk to the Nation of

potential strategic material shortfalls. The structure and the assessments are documented in the *2013 Report on Stockpile Requirements* to the Congress.²

B. Integrated Risk Assessment and Management Model (IRAMM)

IRAMM is used in the third step of the RAMF-SM structure. Step 3 involves a material-specific shortfall assessment, analyzing the risks to the Nation of not doing anything to mitigate specific material shortfalls in the case of interest. A full description of this material shortfall risk assessment may be found in Appendix 12 of the *2013 Report on Stockpile Requirements* to the Congress.³ IRAMM probabilities for the *Base Case*⁴ scenarios are used in several ways in RAMF-SM, especially in estimating the expected costs of mitigation options that would be incurred if the Base Case should occur. In addition to providing probabilities for the Congressionally mandated Base Case scenarios, IRAMM risk findings also provide the future strategic context for the experts who estimate strategic materials shortfall risks.

The core features of IRAMM were developed and documented by IDA under separate contract with the DOD. The Institute for Defense Analyses (IDA) Paper P-4470⁵ provides additional background on IRAMM.

IRAMM has five key features.

1. It enables coherent, structured elicitation of knowledgeable evaluators' estimates of the future probabilities of various significant threat scenarios the United States may confront in the future, some of which may feature disruptions of strategic material supplies to the United States.
2. It helps evaluators identify the adverse consequences to the Nation that would, in their judgment, likely result when using a specified set of forces, military capabilities and related preparedness programs to address a threat, or set of threats, should those scenarios actually occur. Consequences for each potential scenario are explicitly evaluated within IRAMM along three categories (economic, military, and political). These evaluations are then integrated by the respondent, facilitated by the interviewer, into a single, ratio-scaled metric that enables comparisons among scenarios in all phases of the IRAMM elicitation.
3. It allows respondents to express their views on strategic risk⁶ during one-on-one, not-for attribution interviews. Each respondent uses a common risk definition

² DOD, *2013 Report on Stockpile Requirements*, Appendix 12.

³ Ibid, Appendix 12.

⁴ Ibid. Appendix 3.

⁵ James S. Thomason, *IDA's Integrated Risk Assessment and Management Model*, IDA Paper P-4470 (Alexandria, VA: IDA, June 2009).

and scales for estimating consequences so that the results can be used in a group discussion among respondents that follows the interviews. The group discussion is facilitated in order to frame areas of agreement and disagreement. At the end of the group discussion, respondents are provided an opportunity to revise their initial risk scores in light of the evidence and insights of other senior respondents and SMEs.

4. It offers a means by which many promising trades—puts and takes—may be tested up across the entire enterprise in terms that are useful to senior decision makers. While perhaps not perfect in this regard, IRAMM terminology and scales may offer a major improvement in structured decision making.
5. It provides respondents with an opportunity to identify alternative significant threats to the Nation. Respondents may assign their own subjective probability of a scenario’s occurrence and their individual assessment of consequences should it occur. IRAMM is not just a mechanistic application of the standard formula equating risk as the simple product of probability and adverse consequences, as discussed later in the text.

C. Definition of Risk

DOD defines risk as “probability and severity of loss linked to hazards.”⁷ The IRAMM methodology is concerned with *strategic risk* determined in the context of various force structure alternatives. Accordingly, strategic risk is defined to be the predicted political, economic, and military losses or hazards facing the United States, based on the expected *likelihood* and *character* of future events and conditions, assuming currently programmed military forces (or a postulated alternative to those forces and capabilities). There are a number of key facets to this definition that affect how strategic risk (hereafter referred to as risk) is to be measured. Note that risk involves *future* events and conditions. Estimating risk is not simply a matter of analyzing current and historical data; rather, it involves predicting what scenarios might happen and how consequential they will be if they do happen. Specifically, it requires estimating two aspects of future events and conditions: likelihood and character. The IRAMM methodology uses subjective probability⁸ to estimate the likelihood of future events and conditions; it uses

⁶ The strategic risk in IRAMM is not the same as the material shortfall risk estimated in the *2013 Report on Stockpile Requirements*.

⁷ Joint Publication 1-02, *DOD Dictionary of Military and Associated Terms* (Washington, DC: DOD, amended 15 December 2013), 230. The *American Heritage Dictionary* defines risk similarly, as “the possibility of suffering harm or loss.” *American Heritage Dictionary*, 4th Edition, s.v. “risk.”

⁸ Subjective probability is a quantification of uncertainty that obeys the convexity rule, the addition rule, and the multiplication rule. See George Wright and Peter Ayton, *Subjective Probability* (Chichester: John Wiley and Sons, 1994), 4–5.

economic, military, and political consequences to represent the character of future events and conditions.

2. 2012 Risk Assessment Exercise

The IRAMM methodology was recently used in the preparation of a report from the Secretary of Defense to the U.S. Congress entitled *Strategic and Critical Materials 2013 Report on Stockpile Requirements*.⁹ The Strategic Materials Office of the Defense Logistics Agency (DLA) sponsored IDA to conduct an exercise to support the risk assessment portion of the analysis. Specifically, IRAMM exercise participants estimated probabilities of occurrence for two versions of the Base Case set of scenarios used to assess wartime demand and supply of strategic materials. (See sub-section 2.C.3) In addition, IRAMM exercise participants' qualitative descriptions of potential strategic consequences of the Base Case scenarios (see sub-section 2.C.2) provided strategic context to a panel of materials experts who contributed separate estimates of consequences of specific material shortfalls. Exercise participants also estimated probabilities of occurrence for *peacetime supply disruption* scenarios.

A. Background

In the IRAMM exercise, participants estimated levels of risk to U.S. national interests in four distinct categories of military missions: Major Combat, Irregular Warfare, Homeland Defense, and Global Peacetime Operations. The timeframe for the assessment was the ensuing decade, from 2012–2021. Participants assumed that U.S. military forces in the future would be configured as they are in the President's FY2013 budget and associated Future Years Defense Program (FYDP). The IRAMM framework included one-on-one, not-for-attribution interviews with senior leaders that lasted approximately one and a half hours on average.

1. Selection of Experts

The experts chosen for this exercise all had significant experience in the field of national security. Current/retired military members of the group had achieved the rank of flag officer—the majority of them achieving the four-star rank. Current and former civilian government participants were chosen based on their experience at senior levels in the Office of the Secretary of Defense and similar positions in other governmental

⁹ Much of this chapter is based on the Annex, Strategic Risk Assessments, to Appendix 12 of the *2013 Report on Stockpile Requirements*.

agencies responsible for national security. Members with an asterisk by their name were currently in the position cited at the time of the interview.

Experts consulted in the study were: Matthew Beebe,^{*} Deputy Director, Acquisition, Defense Logistics Agency; Frank Carlucci, Secretary of Defense, National Security Advisor to the President; General George Casey, Chief of Staff, U.S. Army; General Kevin Chilton, Commander, U.S. Strategic Command; Dr. David Chu, Undersecretary of Defense (Personnel and Readiness); Admiral Vernon Clark, Chief of Naval Operations; Michael Dominguez, Acting Secretary of the Air Force, Principal Deputy Undersecretary of Defense (Personnel and Readiness); Alan Estevez,^{*} Assistant Secretary of Defense (Logistics and Materiel Readiness); General Carlton Fulford, Deputy Commander, U.S. European Command; General Alfred Gray, Commandant, U.S. Marine Corps; General Michael Hayden, Director, Central Intelligence Agency; General H.T. Johnson, Acting Secretary of the Navy, Commander, U.S. Transportation Command; Robert Manning,^{*} Deputy National Intelligence Officer, Economic Issues; Deborah McWhinney,^{*} Chief Operating Officer, Citi Global Enterprise Payments, Citigroup; Rear Admiral Richard Porterfield, Director for Intelligence, U.S. Pacific Command; Philip Rogers,^{*} Deputy Director, Acquisition Resources Analysis, Office of the Secretary of Defense; General Larry Welch, Chief of Staff, U.S. Air Force; Dr. John White, Deputy Secretary of Defense.

2. Description of Challenge Areas

The risk assessments were structured around four *Challenge Areas*. These four Challenge Areas were defined so that together they covered a full range of potential operations conducted by the U.S. military. The Challenge Areas and their definitions used in this exercise are shown in Figure 2.

Challenge Areas	Definitions
Major Combat	Operations conducted against a state or non-state actor that possesses significant military capability. This area should account for risk related to the use of WMD during the course of major combat. <i>e.g., China, North Korea, Iran, Libya</i>
Irregular Warfare	Stability operations, counterinsurgency, peacekeeping, or counterterrorism operations involving significant participation of U.S. forces in combat or prospective combat. <i>e.g., Iraq, Afghanistan, Bosnia, Somalia</i>
Homeland Defense	Protection of U.S. sovereignty, territory, population, and critical infrastructure against external threats. This area should delineate among risks from WMD, cyber attack, and all other forms of external attack (except those directly related to Major Combat). <i>e.g., 9/11, missile attack, WMD attack, cyber attack, other terrorist attack</i>
Global Peacetime Operations	Operations conducted to influence partners and adversaries. This area should account for risks related to changes in allied or adversary military capabilities, weapons proliferation, or political instability that are contrary to U.S. peacetime military objectives but do not result in U.S. combat operations. <i>e.g., presence, deterrence, building partnership capacity, counter-proliferation, freedom of navigation, humanitarian and disaster response.</i>

Figure 2. Challenge Area Definitions

Respondents were asked to identify potential future scenarios in each of the four Challenge Areas. For each scenario identified, they were asked to estimate (1) the likelihood that the scenario would occur in the next ten years; and (2) the consequences of the scenario given that it occurs using the IRAMM consequence scale. The product of these two parameters generated a risk score.

3. Consequence Categories

The IRAMM Consequence Scale Aid (see Figure 3) is used by respondents to help them measure consequences consistently. Consequences are measured in three categories: economic, military, and political. The consequence scale is based in part on the findings from a 2000 study co-chaired by General Andrew J. Goodpaster.¹⁰ That study presented a hierarchy of U.S. strategic interests in each of these three categories with the highest category defined as “vital” (threatening the survival of the United States as a sovereign Nation), and lesser categories defined in terms of decreasing importance. The criteria for each category

¹⁰ The Commission on America’s National Interests, *America’s National Interests* (Cambridge, MA: Belfer Center for Science and International Affairs, Harvard University, July 2000).

identified in that report were refined to the bullet form that appears in the IRAMM consequence scale aid.

The consequence scale is constructed so that the criteria in each of the three cells in a row have roughly equal consequences¹¹ relative to their category. Since there were five rows, respondents tended to assign consequence scores in five equal-sized bins, from 0–20, 20–40, 40–60, 60–80, and 80–100. However, respondents were not bound to the values implied by the scale developers and were free to assign consequence scores in accordance with their value system on a scale of 0 to 100 or more.

Consequence Scale Aid		
Economic	Military	Political
<ul style="list-style-type: none"> 4% or greater cumulative loss in GDP Extreme, semi-permanent structural and economic costs. Capital flows massively degraded and/or dollar collapses jeopardizing U.S. economic foundation. Alliances and economic agreements terminated. 	<ul style="list-style-type: none"> Loss of more than 10% of overall military force capability; <u>recovery longer than 4 years</u>. Covering worldwide mission areas adequately is impossible. Deterrence severely compromised in key areas. Potential international condemnation due to high non-combatant casualties. Loss of confidence in military, internally and externally. 	<ul style="list-style-type: none"> The U.S. seen as unreliable by multiple allies or coalition partners and new regional security orders emerge. Loss of credibility as guarantor of global security. Allies and friends create their own nuclear arsenals to guarantee their security Competitors become increasingly aggressive and adversarial.
<ul style="list-style-type: none"> 3% cumulative loss in GDP Severe economic costs resulting from trade disruptions, operational factors, or property damage. Capital flows seriously degraded and/or substantial devaluation of dollar. Global economy stalled. Recovery eventually. 	<ul style="list-style-type: none"> Loss of 5-10% of overall military force capability; <u>recovery within 4 yrs</u>. Reduced worldwide mission areas commitment. Deterrence weak in key areas. Critical U.S. vulnerability revealed to all from military surprise. International criticism due to high non-combatant casualties. 	<ul style="list-style-type: none"> U.S. strategic influence severely degraded. U.S. loses credibility in one or more key regions of the world. One or more competitors takes advantage of perceived U.S. weakness. Some coalitions fail; some allies turn away from the U.S.
<ul style="list-style-type: none"> 2% cumulative loss in GDP Serious economic costs due to trade disruptions, operational factors, or property damage. Capital flows degraded and/or value of dollar weakens. Economic disruptions possible, but no recession follows. Reconstruction of key economic capabilities could take months. 	<ul style="list-style-type: none"> Loss of 1-5% of military force capability; <u>recovery within 18 months</u>. Worldwide mission areas still covered. Overall mission success not questioned. Deterrence weaker, but still strong. High non-combatant casualties. 	<ul style="list-style-type: none"> U.S. weakened as major global political broker. International cooperation with U.S. put at risk. U.S. credibility weakened with one or more competitors. U.S. partners doubt U.S. commitment and begin to forge separate security arrangements or seek unilateral measures to guarantee their security.
<ul style="list-style-type: none"> 1% cumulative loss in GDP Some economic costs due to trade disruptions, operational factors, or property damage. Confidence quickly restored domestically and internationally. 	<ul style="list-style-type: none"> Loss of <u>less than 1%</u> of military force capability. Worldwide mission areas covered adequately. Low or predicted non-combatant casualties. 	<ul style="list-style-type: none"> Some political opposition to and suspicion of U.S. intentions in previously friendly countries. Reduced willingness of allies and friends to cooperate with U.S. on other international security goals.
Negligible effect on GDP	<ul style="list-style-type: none"> No major loss of military force capability overall. Worldwide mission areas covered adequately. Low or predicted non-combatant casualties. 	<ul style="list-style-type: none"> Some minor political opposition to and suspicion of U.S. intentions in previously friendly countries.

Figure 3. Consequence Scale Aid

¹¹ IDA subject matter experts developed the criteria used in the scales. Each of the consequence categories was developed as an ordinal scale with the severity of consequences ordered from most to least in each category.

B. Description of Elicitation Protocol

The interview begins with a brief overview of the IRAMM methodology. The heart of the elicitation protocol consists of requests for the respondent to

- identify scenarios within each Challenge Area that cause risk in the time period specified
- estimate the probability of occurrence for each of the identified scenarios
- estimate the consequences associated with each scenario for a specified force structure.

Consequences for all scenarios identified by respondents are compared to the consequences for the calibration scenario, and, as the exercise progresses, to previously estimated scenario consequences. Respondents are asked to provide a *ratio value* for comparison (e.g., a given scenario is “½” as consequential as the calibration scenario). The summation of the risk scores for all the scenarios in a Challenge Area is a measure of the overall risk for that Challenge Area.

1. Consequence Calibration

Short scenario descriptions were defined to serve as calibration points for the top and the bottom of the 100-point scale (see Figure 4 for an illustration).

Calibration Points for Consequence Estimates

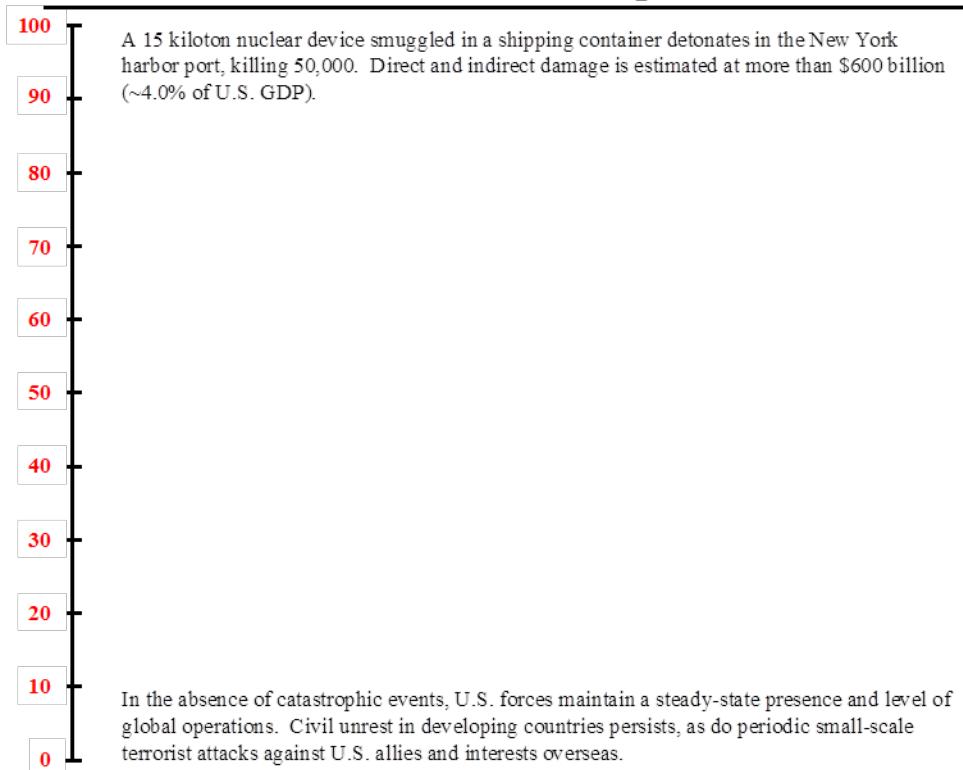


Figure 4. Consequence Calibration Points

A scenario involving a nuclear attack on the U.S. homeland was used as the calibration scenario and assigned an overall consequence value of 100. This does not imply that this scenario scores 100 on each of the consequence categories—political, military, and economic—should it occur. Rather, its function is to provide a starting point for respondents as they assess the consequences of scenarios. Another scenario depicting no significant military events over the 2012–2021 decade was associated with the bottom of the scale, representing a consequence score of effectively 0 on the 100-point scale. Initially, respondents were asked to estimate their consequence scores for the scenarios they identified in relation to these calibration points. As the exercise matures, respondents can use previously assessed scenarios as points of pairwise comparison¹² for each new scenario, thus helping to insure the internal consistency of their answers as well as providing the fundamental basis for using the product of probability and consequences as a risk metric. Respondents deemed almost all of the scenarios they identified to be less consequential than the high-end of the calibration scenarios. In practice, nothing

¹² Using pairwise comparisons to induce ratio-scaled comparisons based on ordinal scales is described in Ward Edwards, “How to use Multi-attribute Utility Measurement for Social Decision Making,” *IEEE Transactions on Systems, Man, and Cybernetics* SMC-7, no. 5 (May 1977): 326–340.

prohibited respondents from estimating consequences that were greater than the 100 assigned to the calibration scenario, and a few respondents chose to do so.

Respondents used the scales in the following way. For each scenario they identified within a given Challenge Area, they were asked to provide (1) the probability that the scenario would occur in the next decade; and (2) the political, military, and economic consequences of the scenario should it occur using the Consequence Scale Aid and the calibration scenarios.

The risk assessment for each scenario was produced in accordance with the respondent's own value system. That is, for each scenario in the challenge area, respondents were asked to estimate the political, military, and economic consequences separately; the respondents were then asked to combine them. The method of combination was left to their discretion, although most chose to average the consequences.

Throughout the elicitation process, respondents were asked to provide pairwise comparisons between consequence estimates for new scenarios and consequence estimates for previously assessed scenarios. This step helps ensure consistency in their risk judgments. For example, a respondent who had estimated an overall consequence score of 40 would be asked to verify that this scenario was twice as consequential as one they had assessed earlier to have a score of 20. Similarly, pairwise comparisons were made for risk estimates (the product of probability and consequences) of different scenarios. The interviewer would also ask the respondent to compare total risk estimates for a just completed Challenge Area to previously completed Challenge Areas. For example, at the end of the elicitation for the Irregular Warfare (IW) Challenge Area, a respondent with a total risk score of 30 for IW and a total risk score of 10 for Major Combat Operations (MCO) would be asked to confirm the total risk for IW was "three times as risky" to U.S. vital national interests as the MCO Challenge Area. Thus, at the end of each Challenge Area, the respondent was given the opportunity to change his or her risk estimates to maintain consistency across Challenge Areas. A useful tool for helping the respondent to visualize his/her responses was the *risk profile*. Figure 5 shows a notional risk profile for Challenge Areas A through D.

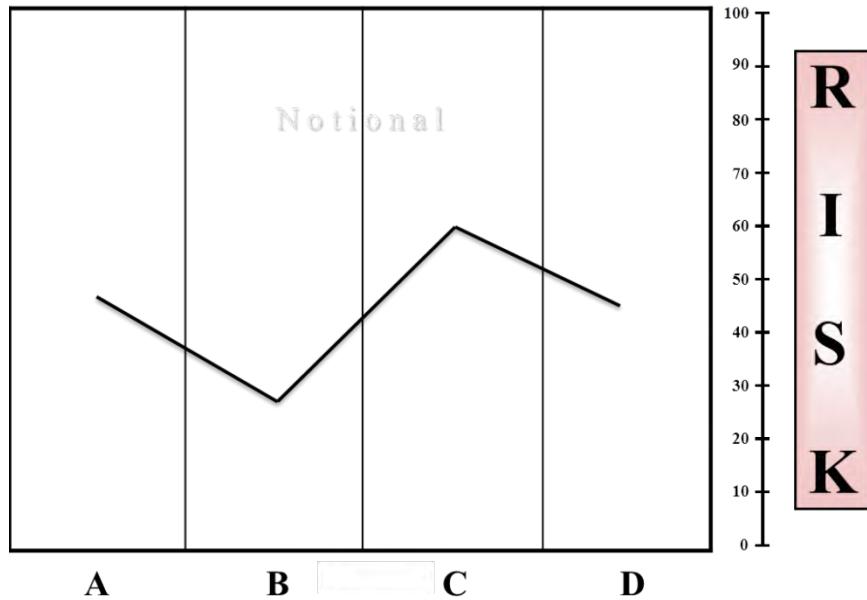


Figure 5. Notional Risk Profile

2. Order of the Elicitation

For consistency, the Challenge Areas were presented in the same order for each respondent, as follows: Major Combat Operations, Irregular Warfare, Homeland Defense, and Global Peacetime Operations. This order was intentional and important to the elicitation protocol. The interviewer starts with MCOs as all the scenarios in this Challenge Area are discrete events with—as it turns out—relatively low likelihood of occurrence. This enables the use of *event trees*,¹³ a structure that helps the respondent assess probabilities consistently. Assessing the MCO Challenge Area first allowed the respondents to become familiar with the idea of combining the two elements of risk (likelihood and consequences) before they were introduced to the phenomenon of consequence aversion. In contrast, the Global Peacetime Operations Challenge Area was saved for the end of the exercise. Scenarios in this area pose a much different challenge regarding assessment of likelihood as they often involve on-going operations that lack well-defined beginning and end points. Additionally, these operations are often seen as mitigating risk rather than adding to U.S. risk. The IDA team found that the prior results of assessing risk in the first three Challenge Areas helped prepare the respondent for assessments of these complex phenomena.

¹³ See Chapter 3 of this paper for a definition of event trees.

C. Results

This section presents some major results from the 2012 IRAMM exercise. The first sub-section presents risk profiles that provide a graphical summary of respondents' quantitative views of risk by Challenge Area. The second sub-section presents a summary of qualitative comments that support respondents' quantitative assessments of risk. The final sub-section discusses how the probabilities of particular scenarios were used to help produce the *2013 Report on Stockpile Requirements* to Congress.

1. Risk Profiles

Figure 6 depicts the actual risk estimates of each respondent for each Challenge Area.

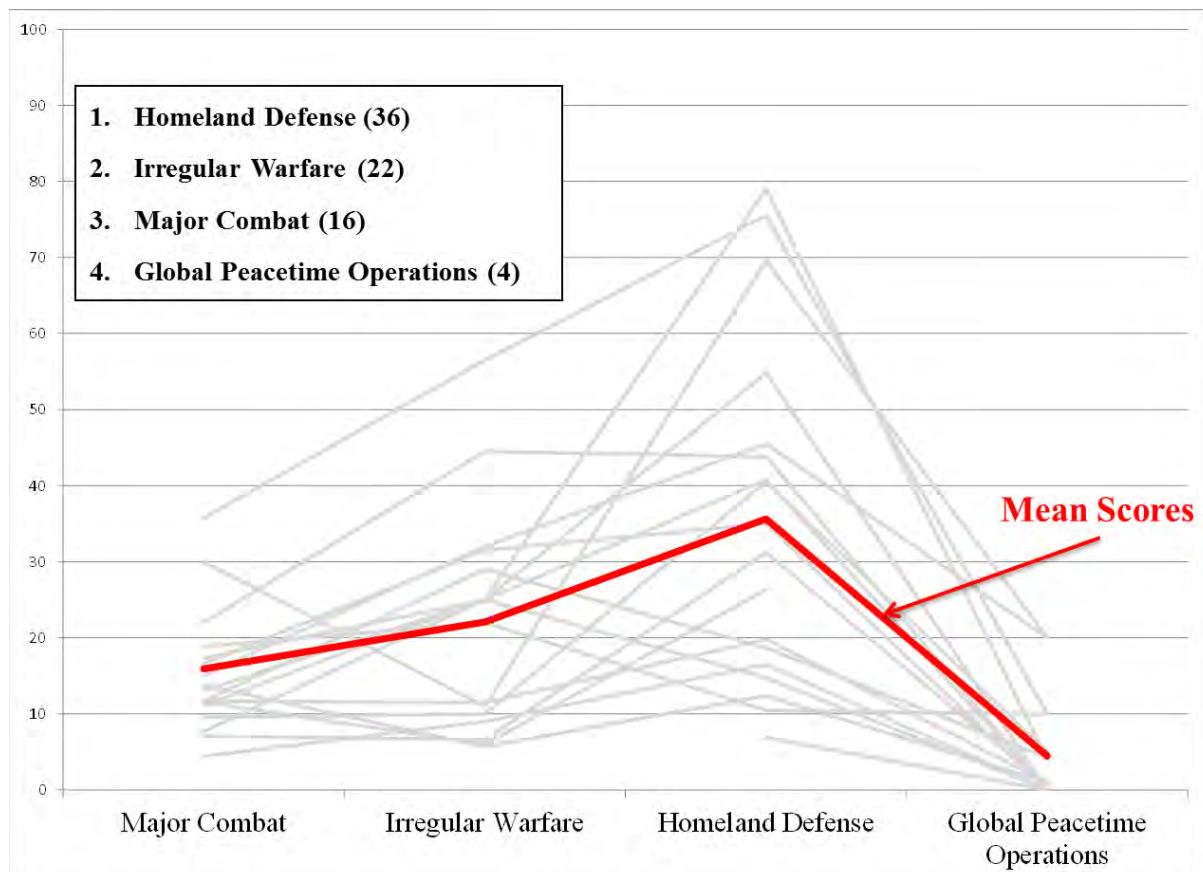


Figure 6. Risk Profile Results

This graphic was useful in answering the question, "How did I compare to the other respondents?", which was a common question that respondents asked following the elicitation; it also served to facilitate discussions among the respondents in the panel session that followed the interview. The lines connecting the risk estimates make it easier for the respondent to *see* his/her risk profile and compare it to those of other respondents.

A major objective of IRAMM risk interviews and the findings they produce is to structure and enrich comprehensive discussions of U.S. strategic risks among senior leaders. This objective was met as each respondent wrestled with the question, “Why is my risk profile different from the risk profile of other respondents?” The line on the chart labeled *Mean Scores*¹⁴ offered another way to compare themselves to their peers. The means for each Challenge Area (the number in parenthesis after each Challenge Area) also provided the respondents with a way to compare the magnitude of the risk estimates across Challenge Areas using a ratio scale.

2. Drivers of Risk

Major quantitative results can be summarized in the following four observations referred to as *majority viewpoints*. Each majority viewpoint is supported by qualitative comments from respondents referred to as *drivers of risk*.

- **Majority Viewpoint #1:** Most (67 percent) participants saw more strategic risk in Homeland Defense scenarios than any other category of military missions.

Drivers of Risk: Participants identified more risk in cyber-attack scenarios than in other types of scenario, driven by judgments that a significant successful attack is both relatively likely and would have relatively large consequences. Nuclear and biological attack scenarios were also seen as relatively high risk, with severe consequences not only in terms of civilian casualties, but also in enduring psychological and economic effects.

- **Majority Viewpoint #2:** Even with the Iraq war over, and the Afghanistan drawdown underway, most (67 percent) participants saw more strategic risk in Irregular Warfare than in Major Combat Operations.

Drivers of Risk: Operations in Afghanistan will continue to be costly, and the outcome will likely be unsatisfactory. While the United States may choose not to launch another stability operation of the same scale as Operation Iraqi Freedom or Operation Enduring Freedom, irregular warfare will be very hard to avoid altogether.

- **Majority Viewpoint #3:** Most (67 percent) participants saw war with Iran as the riskiest of all major combat scenarios.

Drivers of Risk: War with Iran was generally considered significantly more likely than war with other nation states, prompted by conflict over

¹⁴ Although the mean is generally not a robust estimator of the central tendency, it served as an appropriate measure in this instance. Other estimators (the median, various trimmed means, and Winsorized means) were investigated; they did not vary significantly from the mean.

Iran's nuclear program or Iranian attempts to coerce its neighbors. The global retaliatory reach of Iran's proxies (e.g., Hezbollah) also elevated participants' estimates of risk related to war with Iran.

- **Majority Viewpoint #4:** All participants believed that strong global military presence and engagement is important to U.S. national interests.

Drivers of Risk: If budget cuts and force structure reductions reduced the U.S. military's ability to maintain forward presence and engagement, then strategic risk would increase in all mission areas caused by eroding deterrence against regional aggression, reduced confidence of allies and partners in U.S. commitment to their security, and greater difficulty maintaining dialogue and cooperation with friends and potential rivals alike.

3. **Estimating Probabilities for the 2013 Report on Stockpile Requirements to Congress**

The *2013 Report on Stockpile Requirements* to Congress contains the DOD assessment of potential U.S. problems regarding strategic and critical non-fuel materials in the context of a congressionally-mandated Base Case planning scenario.¹⁵ The report recommends material-specific mitigation strategies for the problematic materials. To evaluate the utility of various measures for mitigating potential shortfalls of materials that could occur during a national emergency, DLA Strategic Materials developed a risk assessment and shortfall mitigation cost-effectiveness analytical process. The first step in the analysis after identifying the shortfall risk mitigation measures to consider is to assess the existing (unmitigated) risk arising out of potential material shortfalls during the NDS Base Case scenario. Material shortfall risk is taken to be the product of the probability that a material shortfall would occur and the consequence to the nation of the shortfall, that is,

$$\text{Shortfall risk} = P_{\text{scenario}} \times C_{\text{shortfall}}.$$

In the course of the 2012 IRAMM interviews described earlier, respondents provided estimates of the probability of the Base Case scenario.¹⁶

¹⁵ DOD, *2013 Report on Stockpile Requirements*, 1.

¹⁶ Other experts (not IRAMM respondents) estimated the consequences of material shortfalls.

3. Enhancements to the IRAMM Protocol

Based on the use of IRAMM over time in multiple contexts, IDA has identified three areas for improvements to the protocol that they plan to implement prior to the next round of interviews to be conducted in the spring/summer of 2014 in preparation for the *2015 Report on Stockpile Requirements*. These enhancements are described in the subsequent sections.

A. More Complete Scenario Space for Major Combat Operations (MCO)

Though the respondents were experts in the field of national security and defense strategy and forces, they were not, in general, trained in the mathematics of probability theory. Most people understand the idea of probability as a measure of one's belief about an uncertain event; however, studies have shown that humans find it difficult to accurately assess probabilities.¹⁷ The IRAMM methodology employs event trees to the maximum extent possible to mitigate known difficulties in expert probability assessment. For example, if one were to ask a respondent to separately assess the probability of four different events (A through D) occurring in the next decade, the result might be as follows: $P(A) = 0.2$; $P(B) = 0.4$; $P(C) = 0.1$; $P(D) = 0.7$. Some implications of this assessment seem relatively clear: for example, event B is twice as likely as event A; event D is the most likely of the four events, etc. However, there are implications that may not be obvious to some respondents: for example, there is a non-zero probability that more than one of the events will occur in the next decade.

Event trees help make the relationships between the probabilities of different events (scenarios) and combinations of those events clearer to the respondent. A scenario description contains those key elements of a conflict that a respondent needs to consider when estimating consequences (e.g., United States/allied forces, adversarial forces, goals and constraints for both sides, etc.). Since respondents identify the scenarios that he or she foresees as potentially occurring in the coming decade, the information that describes those scenarios is part of their thought process, and hence can differ by individual. The elicitation draws out and records their scenario information and thinking, by asking

¹⁷ See, for example, A. Tversky and D. Kahneman, "Judgments under Uncertainty: Heuristics and Biases," *Science* 185 (November 1961): 1124–1131. See also Robin M. Hogarth, *Judgment and Choice: The Psychology of Decisions* (Australia: John Wiley and Sons, 1980).

questions such as, “how do you see the scenario playing out” and by comparing their consequence estimates with the consequences assigned to the calibration scenario and to other scenarios they have previously assessed.

To build an event tree, the respondents were first asked the following question: “What is the probability that the United States will become involved in one or more Major Combat Operations during the next ten years?” Respondents typically provided either percentage (e.g., 40 percent) or chances out of ten (e.g., four chances out of ten). Respondents were then asked the following question to confirm their estimate: “Does this mean that you believe there is a 60 percent chance that no MCOs will occur in the next ten years?”, thus permitting the respondents to refine their answers. The initial branches of the event tree are called Level I branches. All branches that stem from the Level I branches are called Level II branches, and so on for the construction of the complete tree. All of the probabilities assigned to the branches for Level I of the tree must sum to 1.0. This is true for all levels of the tree. Figure 7 is an example of an event tree with two branches on Level I.

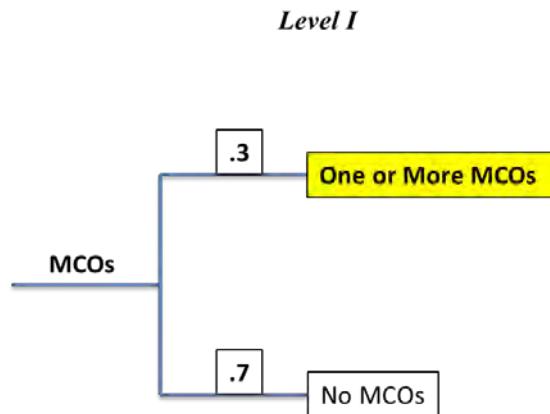


Figure 7. Level I of an Event Tree

All probabilities assigned in an event tree are conditional based on the state of the branch from which they stem. The terminal branches of an event tree represent the scenarios that the respondent has identified, and the probabilities for each of these scenarios are computed by multiplying the probabilities along the path of branches that lead to the *end node* on the last level. By construction, all the scenarios represented on the end nodes of the tree are mutually exclusive. Since the end nodes represent specific scenarios, respondents may find it easier to estimate the probability for the scenario as the joint probability for the end node (the product of the probabilities on the branch path to the end node). This is illustrated in Figure 8.

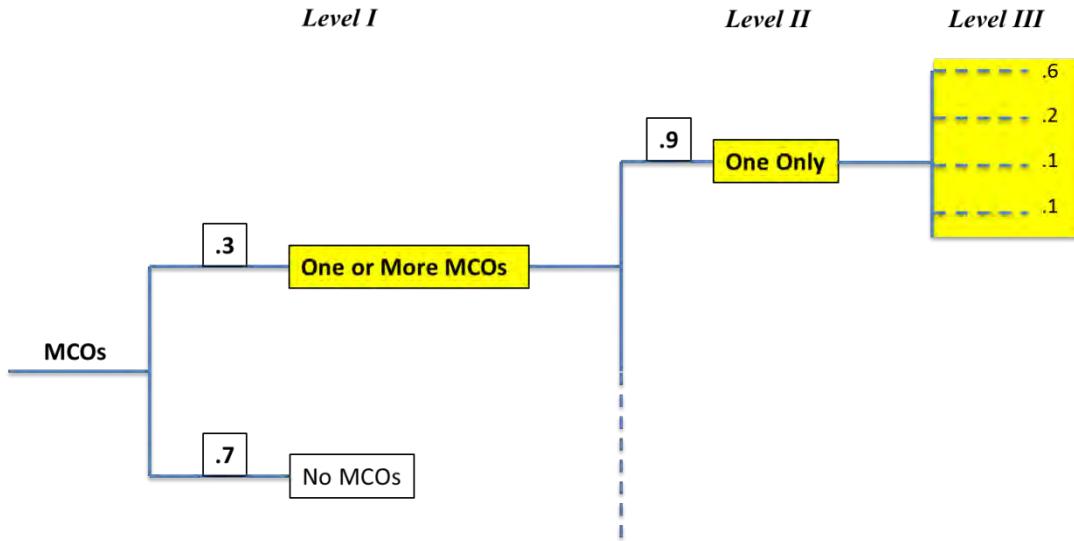


Figure 8. Event Tree for MCOs

During the interviews conducted in 2012, respondents were asked to identify all of the scenarios in the coming decade that they could foresee as causing risk. Although respondents had the opportunity to specify that more than one MCO might occur in the time frame, the interviewer did not specifically elicit the probability of this and consequently respondents did not do this frequently. The improved protocol (illustrated in Figure 9) is designed to specifically elicit the probability of multiple MCOs.

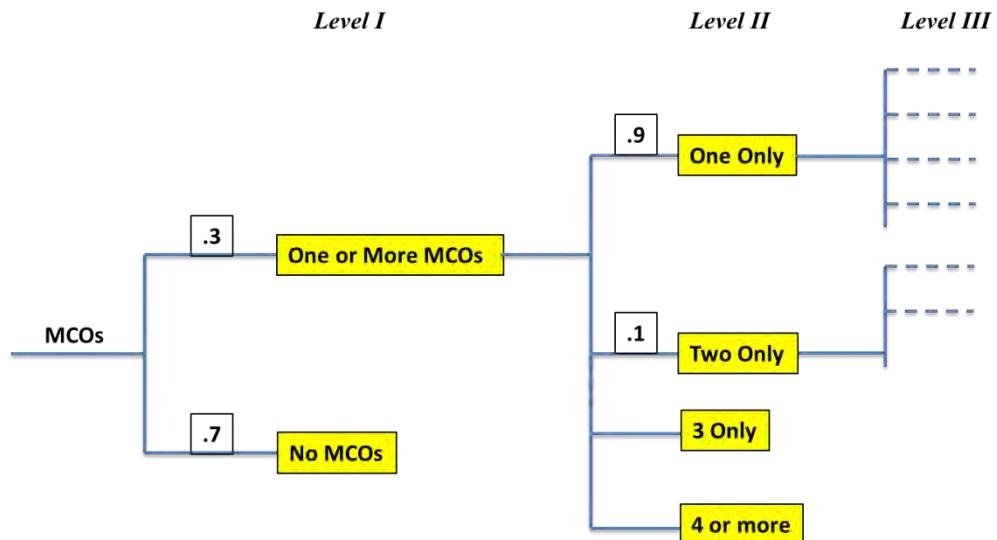


Figure 9. New Fuller Event Tree for MCOs

In accordance with the narrative above, respondents will be formally asked the probabilities for the branches: I only, II only, etc. Incorporating these extended protocols

will help to improve the rigor of accounting for all scenarios, but will also add time to the interview.

B. A Different Approach for the Irregular Warfare (IW) and Homeland Defense (HLD) Challenge Areas

There is general consensus for defining risk to include two metrics: likelihood and character. However, there is no consensus on how to quantitatively measure risk in a way that faithfully includes both of these facets of risk. Nevertheless, it is common¹⁸ to estimate risk by using the product of probability and consequences. This is how risk has been quantified in the IRAMM methodology. The 2012 interviews highlighted that the product is not the best approach to quantifying risk in some situations, because it does not appropriately represent the respondent's underlying *beliefs* about risk. In future versions of the IRAMM protocol, the product of probability and consequences will not be used exclusively to estimate risk.¹⁹

Kaplan and Garrick best described one issue with using the product of probability and consequences when they stated, "In the case of a single scenario the probability times consequence viewpoint would equate a low-probability high-damage scenario with a high-probability low-damage scenario—clearly not the same thing at all."²⁰ There are other issues such as *sunk cost* that also complicate assessing risk. The ensuing paragraphs present an example that illustrates these and other issues, by comparing the risk associated with two hypothetical scenarios—one in the Irregular Warfare Challenge Area and the other in the Homeland Defense Challenge Area.

In the IW area, some scenarios are ongoing and have been for years (e.g., Operation Enduring Freedom). Hence the probability of the scenario occurring is 1.0 and one can reason that the consequences of remaining operations are low—certainly in comparison to the consequences that have already been realized since the beginning of operations. Even so, respondents are reluctant to provide extremely low consequence scores when the lives of American soldiers are still at risk and budgets above and beyond the budget for *normal* peacetime operations are still being allocated. Another influence on respondents' judgments is the large sums of money and lives that have already been spent. In these cases, respondents typically provided a consequence score of 5, 10, or more for these types of operations.

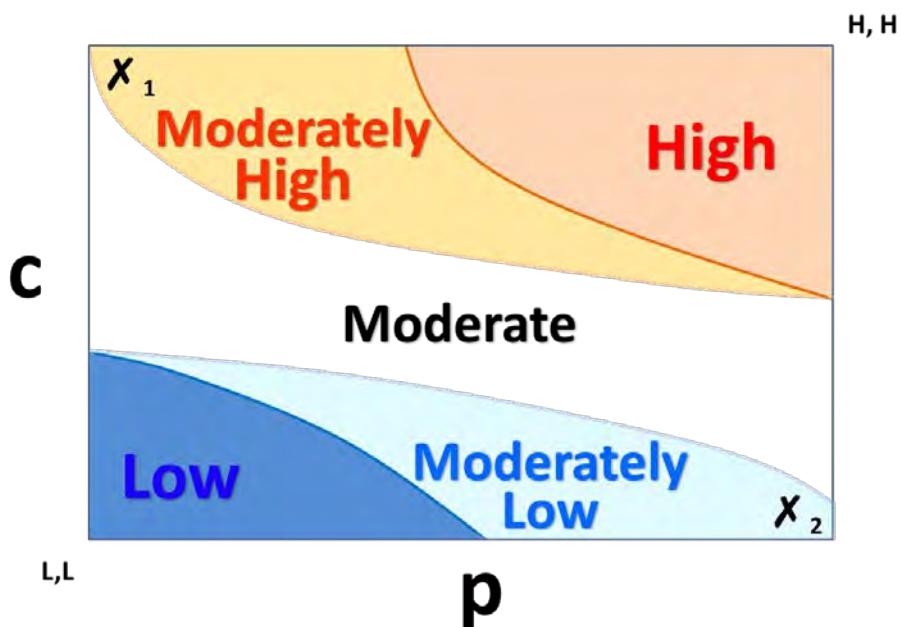
¹⁸ See for example, Bilal M. Ayyub, *Elicitation of Expert Opinions for Uncertainty and Risks* (Boca Raton: CRC Press, 2001), 104. See also Tim Bedford and Roger Cooke, *Probabilistic Risk Analysis: Foundations and Methods* (Cambridge: Cambridge University Press, 2001), 10.

¹⁹ In the 2012 interviews, respondents were free at the end of their interviews to adjust their calculated risk scores by Challenge Area, and some, in fact, did so.

²⁰ Stanley Kaplan and John B. Garrick, "On the Quantitative Definition of Risk," *Risk Analysis* 1, no. 1 (1981): 13.

In the HLD arena, consider a scenario consisting of a nuclear device detonated in a large U.S. metropolitan area to which the respondent assigns a probability estimate of 1/100 and a consequence score of 100. The product of probability and consequences results in a risk score of 1. When compared to the previous Operation Enduring Freedom example with risk scores of 5 to 10, many respondents felt that these comparative risk scores did not accurately represent their beliefs. They indeed believe that the risk associated with a nuclear detonation in a large U.S. city was higher than the risk associated with the remaining mission in Afghanistan.

Kaplan and Garrick go on to assert that, “A single number is not a big enough concept to communicate the idea of risk.”²¹ Accordingly, they propose that, “It takes a whole family of curves to fully communicate the idea of risk.”²² These findings led to the development of the following chart (Figure 10).



The two X s represent ordered pairs of probability (p) and consequences (c) for two different scenarios resulting in roughly equal risk scores ($p \times c$). Yet, due to consequence aversion, many respondents view the scenario associated with X_1 as riskier than the scenario associated with X_2 .

Figure 10. Consequence Aversion

While it is true that information is lost when two parameters are combined into one, it is a necessary sacrifice in the context of the IRAMM interviews. There is not enough

²¹ Ibid., 14.

²² Ibid.

time to develop these curves; more importantly, this technique would not serve the main objective of the interviews. The purpose of the interviews is not to estimate risk per se, but rather to structure conversations among senior leaders to help enable better decisions.²³ Estimating risk as a single number helps to meet this objective. Nevertheless, the issue of equal risk scores for two potentially very different scenarios needs to be addressed. In the new IRAMM protocol, the chart in Figure 10 is shown to respondents during the interview along with a statement that they are allowed to develop risk scores that are not simply the product of probability and consequences. They initially decide their risk score using the product formula; they are free to adjust this score based on pairwise comparisons with other scenarios. This further implies that the sequence of Challenge Areas used in the interview should start with scenarios that lend themselves to assessing risk on the basis of the product of probability and consequences (e.g., MCOs). Risk for MCO scenarios can then become the basis for comparing risks in the context of the curves in Figure 10.

C. Changes to Challenge Areas

Two changes are being made to the 2012 Challenge Areas. One is dropping the Challenge Area called Global Peacetime Operations. As the name suggests, this Challenge Area included operations that served to strengthen the U.S. defensive posture through activities like military-to-military cooperation obtained from activities such as Joint exercises and training with foreign militaries. These and other similar activities that fell into this challenge area were viewed as opportunities rather than risks. That is, the consequences were positive and could not be measured on the IRAMM consequence scales. Since IRAMM focuses on risk, this Challenge Area was dropped.

Another change is to divide the Homeland Defense Challenge Area into two components: Weapons of Mass Destruction (WMD) against the Homeland, and Cyber Risks to the Homeland.²⁴ One of the principal drivers for this change is the recent emphasis the USG is placing on cyber threats to the U.S. infrastructure. This change highlights one of the features of IRAMM; Challenge Areas are developed to support the needs of the senior decision maker.

²³ As mentioned in Chapter 2, the interviews also produced estimates of the probability of the Base Case scenario for the *2013 Report on Stockpile Requirements*.

²⁴ There are, of course, other threats to the homeland than just attacks involving WMD and cyber. In the 2012 interviews, threats to the homeland exclusive of these categories were elicited; however, the risk assigned by respondents to these other threats was insignificant compared to WMD and cyber.

4. Origin, Value, and Other Applications of IRAMM

In early 2004, three offices in the Office of the Secretary of Defense (OSD), Program Analysis and Evaluation (PA&E), Acquisition, Technology, and Logistics (AT&L), and Policy, along with the Joint Staff, J-8, asked IDA to develop a cross-capabilities assessment and integrated risk management analytic framework that could be used to compare alternative force mixes. The result was IRAMM.

The premise of the IRAMM methodology is that the goal of national security and defense strategy is to mitigate overall risk to the Nation, and therefore, the concept of risk to the Nation is the appropriate vehicle for a process that supports strategic decision making. Accordingly, a formalized, quantified measurement of strategic risk can be one useful means for discriminating among alternative policy and program options. Establishing a viable, comprehensive process for senior decision makers to compare the relative merits of alternative policy and program options in mitigating risks to the Nation—strategic risk—as they are making major defense program decisions has been the chief goal of IDA researchers in building IRAMM.

The approach to assessing risk described in this paper is a rigorous way of obtaining DOD senior leadership views on strategic national security strategy, capabilities, and risk. The results can be used in a multitude of ways including informing the debate on complex issues, identifying alternative resource strategies, allocating resources, developing rationale for decisions, etc.

Previous applications and the flexibility of IRAMM suggest more areas of application. IRAMM would prove useful in any situation where decisions are needed across disparate areas of concern. The IRAMM methodology provides a hedge against the tendency to *sub-optimize* in each area of concern rather than consider the entire *scenario space*. IRAMM accomplishes this by providing a common metric that can be used to compare options associated with each area of concern.

In addition to providing a common framework with common metrics and terms for the advisors to a decision maker, IRAMM can simultaneously serve as a team-building exercise. The interviews and the subsequent group discussion provide a forum for inter-agency dialogue.

A key feature of the elicitation protocols used in IRAMM is that it can be structured to conform to and support the needs of any senior decision maker in a hierarchical command or management framework. The overarching goals of the IRAMM elicitation framework are (1) to provide a *common value system* within which the principal advisors in the management framework can express their views on risk; (2) to create an environment for these senior advisors to *express and share their viewpoints*; (3) to enable a focused discussion among these advisors that provides an opportunity to *express differences of opinion with the potential to build consensus* among the participants; and (4) to synthesize the discussions—both agreements and disagreements—to *provide a basis for the senior decision maker to issue clear guidance* on risk mitigation priorities.

There are other potential uses for IRAMM outside the arena of decision making. For example, it could provide the basis for a training exercise at senior military schools. The exercise would help educate the officers in the value of structured approaches to making decisions. It would also broaden their thinking on the risks to the Nation as well as approaches to mitigate those risks.

By January 2015, the Secretary of Defense is once again required by law (Section 14b of the Stock Piling Act)²⁵ to submit an assessment to the Congress of strategic and critical material risks to the Nation as well as appropriate strategies and recommendations to mitigate them, including but not limited to acquiring Federal inventories for the National Defense Stockpile. To prepare these assessments and recommendations, DOD is employing the RAMF-SM framework, and the IRAMM strategic risk evaluations are an integral part of RAMF-SM. Toward this end, a new round of one-on-one IRAMM elicitations (and one or more group sessions), will be conducted in 2014 utilizing the new IRAMM protocol described in this paper. The results of these IRAMM evaluations, both by senior decision makers and other subject matter experts, will explicitly inform the RAMF-SM assessments and the *2015 Report on Stockpile Requirements* to Congress.

²⁵ Section 14., Biennial Report on Stockpile Requirements, [50 U.S.C. 98h-5], *Strategic and Critical Materials Stock Piling Act*, as Amended through P.L. 112-239, enacted January 2, 2013.

Appendix A

Illustrations

Figure 1. RAMF-SM Process and Steps	2
Figure 2. Challenge Area Definitions	9
Figure 3. Consequence Scale Aid	10
Figure 4. Consequence Calibration Points.....	12
Figure 5. Notional Risk Profile.....	14
Figure 6. Risk Profile Results	15
Figure 7. Level I of an Event Tree	20
Figure 8. Event Tree for MCOs	21
Figure 9. New Fuller Event Tree for MCOs	21
Figure 10. Consequence Aversion	23

Appendix B

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Appendix C

Abbreviations

AT&L	Acquisition, Technology, and Logistics
DOD	U.S. Department of Defense
FYDP	Future Years Defense Program
GDP	Gross Domestic Product
HLD	Homeland Defense
IDA	Institute for Defense Analyses
IRAMM	Integrated Risk Assessment and Management Model
IW	Irregular Warfare
MCO	Major Combat Operation
NDS	National Defense Stockpile
OMB	Office of Management and Budget
OSD	Office of the Secretary of Defense
PA&E	Program Analysis and Evaluation
RAMF-SM	Risk Assessment and Mitigation Framework for Strategic Materials
SME	Subject Matter Expert
U.S.	United States
USG	U.S. Government
WMD	Weapon of Mass Destruction

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